Pulmonary Function Before Surgery for Pectus Excavatum and at Long-term Follow-up*


Pulmonary function tests were performed before surgery on 152 patients who were operated on for pectus excavatum between 1970 and 1987 and at long-term follow-up to assess the degree of impairment and to investigate any changes caused by surgical correction. The mean age at surgery was 15.3 ± 5.5 years. Pulmonary function was found to be restricted preoperatively. Multivariate analysis showed that preoperative pulmonary function was not related to age, the severity of the deformity at physical examination, or to pulmonary complaints. Only the patients with obstructive disease showed significantly more pulmonary complaints (p = 0.042). The total lung capacity (TLC) and inspiratory vital capacity (IVC) were significantly related to the age-corrected (8) anteroposterior diameter of the chest (lower vertebral index [LV1]) (p = 0.0001). At follow-up (mean, 8.1 ± 3.6 years), the restriction of pulmonary function was increased despite improvement in the symptoms of most patients and despite a significant increase in the anteroposterior diameter of the chest (p = 0.0001): the TLC was decreased from 83.7 percent predicted (pred) preoperatively to 73.8 percent pred (p = 0.0001) and the IVC from 78.3 percent pred to 70.7 percent pred (p = 0.0001). The surgical results were satisfactory in 83.6 percent. No relation was found between the changes in pulmonary function measured at follow-up and the surgical results. Only the age at surgery and the changes in the TLC and IVC at follow-up were significantly related (p = 0.0036, 0.0043, respectively), although the correlation coefficients were low (r = 27 percent and 28 percent, respectively). The reduction in lung function at follow-up was most pronounced in the patients who had the least functional impairment (TLC > 75 percent pred) preoperatively. No correlation was found between the changes in the pulmonary function test results at follow-up and follow-up interval, preoperative LV1, and the changes in LV1 at follow-up.

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\[ \text{IVC = inspiratory vital capacity; LV1 = lower vertebral index; RV = residual volume; TLC = total lung capacity} \]

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Indications for the surgical treatment of pectus excavatum mainly concern cosmetic and psychological problems. However, cardiorespiratory symptoms were present in a considerable percentage of the patients preoperatively and were influenced positively by surgery. Whether subjective clinical improvement after surgery results from alterations in cardiopulmonary physiology has remained controversial. Preoperative and postoperative comparisons of lung volumes in patients yielded variable results. Some studies reported an increase in the inspiratory vital capacity (IVC) and total lung capacity (TLC), whereas more recent studies showed a significant worsening or no change after a cosmetically successful operation. In our study, the preoperative and long-term follow-up pulmonary function test results in a group of 152 consecutive patients who were operated on for pectus excavatum were compared retrospectively. The aim was to assess whether and to what extent pulmonary function is impaired in patients with pectus excavatum, and to investigate the changes in pulmonary function caused by surgical correction. Preoperative pulmonary function in patients with pectus excavatum will be related to cardiorespiratory symptoms, physical examination findings, and chest radiographic measurements. The correlations between changes in the lung function parameters and chest diameter or subjective satisfaction are described.

**METHODS**

Between 1970 and 1987, 192 patients underwent surgical repair for pectus excavatum. Only the patients who could be questioned and examined personally at the outpatients department were included in the study (N = 152; 79 percent). Of these patients, 77 percent were male and 23 percent were female. The mean age at surgery was 15.3 ± 5.5 years (range, 4.8 to 32.7 years). They were divided into age groups so that each group contained about the same number of patients to facilitate statistical analysis (group 1 [n = 24], 0 to 9 years; group 2 [n = 24], 9 to 13 years; group 3 [n = 25], 13 to 15 years; group 4 [n = 19], 15 to 17 years; group 5 [n = 36], 17 years; group 6 [n = 40], ≥18 years).
followed children medics, (FEy1) tional viations ing body.'5 Predicted this study. Values were expressed in percent predicted values in accordance with Zapletal et al15 for children and the European Respiratory Society15 for adults. The measurements were performed twice: 3 days before the operation and during the visit to the outpatients department for the purpose of this study.

The presence of sternal depression and the degree of depression were evaluated from the lateral chest radiographs (Fig 1). We used a modification of the vertebral index, described previously,14 to classify the patients. At the level of the xiphisternal junction, a line was drawn perpendicular to the vertebral body and the lower vertebral index (LVI) was calculated by dividing the vertebral body diameter at that level by the distance between the xiphisternal junction and the posterior border of the vertebral body.15 Derveaux et al15 measured the LVI in a group of 250 healthy individuals and found that it was age dependent. Predicted values for the various age groups can be calculated using the formula 0.193 (1−0.326×e−0.258×age). Age-corrected deviations from normal (ΔLVI) were calculated by dividing the difference between the measured LVI and the predicted LVI for a particular age by the standard deviation of the predicted value at that age. A positive value meant that the LVI was higher than normal and thus the posteranterior diameter was smaller than normal.

The operation consisted of subperichondral chondrectomy of all deformed rib cartilages, transverse sternotomy and division of the intercostal bundles at the outer limit of the chondrectomy, and suturing the edge of this broad sheet of muscle and perichondrium to the anterior surface of the chest wall more laterally and under tension, thus elevating and stabilizing the sternum.5,16,17 This technique avoided the use of internal support or external traction and remained unchanged during the study period.

Results were graded according to Humphreys and Jaretzki18 and were termed "excellent" if the chest appeared to be normal, the scar was inconspicuous, and the symptoms, if any, had gone. If there was any residual or recurrent sternal depression or if the scar was bothersome, but in general the patient and the family were satisfied, the result was called "good." Excellent and good results were considered "satisfactory." In patients with persistent pain, unsightly scars, or sufficient asymmetry to cause embarrassment, but whose sternum was in a better position than before the operation, the results were termed "fair." If a second operation had been performed or was considered to be indicated, the result was termed "poor." Fair and poor results were considered "unsatisfactory."

Categoric data were arranged in contingency tables and Fish-
Table 1—Percentage of Patients With Physical Symptoms Before the Operation and at Follow-up

<table>
<thead>
<tr>
<th>Symptom</th>
<th>Preoperative</th>
<th>Follow-up</th>
<th>( p )</th>
<th>Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diminution of exercise tolerance</td>
<td>51.3%</td>
<td>36.0%</td>
<td>&lt;0.02</td>
<td></td>
</tr>
<tr>
<td>Shortness of breath on exertion</td>
<td>31.6%</td>
<td>20.0%</td>
<td>&lt;0.02</td>
<td></td>
</tr>
<tr>
<td>Frequent upper respiratory tract infection</td>
<td>26.3%</td>
<td>13.0%</td>
<td>&lt;0.02</td>
<td></td>
</tr>
<tr>
<td>Frequent lower respiratory tract infection</td>
<td>17.2%</td>
<td>6.0%</td>
<td>&lt;0.02</td>
<td></td>
</tr>
<tr>
<td>Asthmatic bronchitis</td>
<td>7.2%</td>
<td>4.0%</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>Precordial pain</td>
<td>16.4%</td>
<td>12.0%</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>Palpitations</td>
<td>13.2%</td>
<td>13.0%</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>Dizziness</td>
<td>11.2%</td>
<td>11.0%</td>
<td>NS</td>
<td></td>
</tr>
</tbody>
</table>

*p value for difference follow-up vs preoperative. NS = not significant.

RESULTS

Cardiorespiratory symptoms were observed in a considerable percentage of the patients preoperatively, including decreased exercise tolerance (51.3 percent), easy fatigability (43 percent), inability to take deep breaths (37.5 percent), and shortness of breath, mainly on exertion (31.6 percent). Surgery was indicated for psychologic/cosmetic reasons in 55.2 percent and for physical symptoms in 30.5 percent. In 5.3 percent of the patients, the prospect of physical symptoms in the future was the main reason for surgery. At long-term follow-up, most of the cardiorespiratory symptoms were less apparent (Table 1).

During physical examination, the severity of the deformity in our patients was estimated by the surgeon and considered to be severe in 68.9 percent, moderate in 16.9 percent, and mild in 14.2 percent. There were two patients with Marfan’s syndrome. The deformities were classified according to Chin. Type 1 symmetric and localized deformity was seen in 33.2 percent, type 2 symmetric but diffuse deformity was seen in 23.7 percent, and type 3 localized or diffuse asymmetric deformity was seen in 43.1 percent.

The preoperative mean LVI was \( 0.36 \pm 0.11 \) (predicted, \( 0.18 \pm 0.03 \); \( p=0.0001 \)) and when corrected for age (\( \delta \text{LVI} \)), \( 7.33 \pm 4.66 \) (predicted, \( 0 \pm 1 \); \( p<0.0001 \)), which reflected a significantly shorter anteroposterior distance between the vertebral body and sternum. At long-term follow-up, the \( \delta \text{LVI} \) was significantly decreased (\( -3.30 \pm 4.92; p<0.0001 \)): the lower anteroposterior diameter was significantly increased, but was still significantly different from the predicted value (\( p<0.0001 \)).

Pulmonary function measurements are shown in Tables 2 and 3. The TLC and IVC were reduced in comparison with the normal values for a particular age (\( p=0.0001 \)). During follow-up, the TLC increased due to normal growth, but as a percentage of predicted, it decreased further from \( 83.7 \pm 12.3 \) percent to \( 73.8 \pm 12.1 \) percent (\( p=0.0001 \)). The IVC increased but as a percentage of predicted also decreased from \( 78.3 \pm 13.5 \) percent to \( 70.7 \pm 13.6 \) percent (\( p=0.0001 \)). The RV as a percentage of predicted preoperatively was not significantly different from the normal values, but decreased during follow-up (\( p=0.0001 \)). The RV as a ratio of the TLC, however, was significantly higher than predicted (\( p=0.0001 \)) and decreased during follow-up (\( p=0.0023 \)).

Table 2—Preoperative Pulmonary Function Tests*

<table>
<thead>
<tr>
<th>Measurement</th>
<th>No. of Patients</th>
<th>Preoperative Value</th>
<th>( p ) Value</th>
<th>Difference With Predicted Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>TLC, L, % predicted</td>
<td>115</td>
<td>4.848±1.713</td>
<td>0.0001</td>
<td></td>
</tr>
<tr>
<td>IVC, L, % predicted</td>
<td>105</td>
<td>3.383±1.316</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>RV, L, % predicted</td>
<td>113</td>
<td>1.332±0.541</td>
<td>0.4270</td>
<td></td>
</tr>
<tr>
<td>RV/TLC ratio % predicted</td>
<td>110</td>
<td>28.1±6.3</td>
<td>0.0001</td>
<td></td>
</tr>
<tr>
<td>FRC, L, % predicted</td>
<td>113</td>
<td>2.303±0.887</td>
<td>0.0014</td>
<td></td>
</tr>
<tr>
<td>FEV1, L, % predicted</td>
<td>147</td>
<td>2.784±1.110</td>
<td>0.0001</td>
<td></td>
</tr>
<tr>
<td>FEV1/IVC ratio % predicted</td>
<td>147</td>
<td>82.5±8.2</td>
<td>0.0038</td>
<td></td>
</tr>
</tbody>
</table>

*Mean age at surgery, 15.3±5.5 years.

\( \dagger \) p values by signed rank test.
FRC was reduced compared with the normal values (p=0.0014) and decreased at follow-up from 95.6±24.6 percent to 79.4±16.8 percent (p=0.0001). The lung function parameters that indicate restriction actually deteriorated during follow-up. The preoperative FEV₁ was reduced compared with the normal values for a particular age (p=0.0001). This was a consequence of the low IVC. When the FEV₁ was calculated as a fraction of the IVC, the ratio FEV₁/IVC was found to be normal. Consequently, there was no significant airway obstruction in this group. At follow-up, the FEV₁ increased in absolute terms, but decreased when expressed as a percentage of predicted (p=0.0001). The FEV₁ as a ratio of the vital capacity did not change significantly during follow-up.

We did not find a statistically significant relation between age and most of the preoperative lung function test results (percent predicted) (Fig 2). The correlation coefficient for the preoperative pulmonary function tests as a percentage of predicted with age was below 0.02, with p values that varied from 0.482 to 0.970.

The preoperative ratio between the measured IVC/predicted IVC was not related to pulmonary complaints (p=0.336). On the other hand, we did find a significant relation between the presence of one or more pulmonary complaints (decreased exercise tolerance, easy fatiguability, inability to take deep breaths, and shortness of breath on exertion) and obstructive disease as expressed by the ratio FEV₁/IVC as a percentage of predicted (p=0.042). Symptoms of retrosternal pain and palpitations were not related to preoperative lung function. The severity of the deformity did not influence the various lung functions.

The preoperative TLC, IVC, and FEV₁ as a percentage of predicted were significantly related to the δLVI (p=0.0001); however, relation coefficients were low: -0.452, -0.451, and -0.388, respectively. A significant relation was found between the LVI and the severity of the deformity at physical examination.

![Figure 2](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/21695/ on 04/12/2017)
(p=0.0107); however, there was no significant relation between the severity of the deformity and the results of the various lung function tests. No correlation was found between the δLVI and the preoperative FRC as a percentage of predicted, RV as a percentage of predicted, and the ratio FEV1/IVC as a percentage of predicted.

Graded according to Humphreys and Jaretzki,18 satisfactory results at long-term follow-up were observed in 83.6 percent (excellent, 44.1 percent; good, 39.5 percent). In 25 patients (16.4 percent), the results were unsatisfactory (fair, 10.5 percent; poor, 5.9 percent).

We found no correlation between the changes in the results of the pulmonary function tests measured at follow-up and the surgical results. The changes in the results of the pulmonary function tests at follow-up were correlated with the age at surgery, follow-up interval, preoperative δLVI, and the postoperative change in δLVI (Spearman correlation coefficient). Only the age at surgery and the change in the TLC and IVC at follow-up were significantly related (p=0.0036 and 0.0043, respectively), however, the correlation coefficients were low (r=27 percent and 28 percent, respectively). Other authors14 reported that postoperative reduction in lung function was most pronounced in the patients who had the least functional impairment preoperatively (>75 percent predicted). An evaluation of our data using the Wilcoxon test showed that if the preoperative TLC was more than 75 percent of predicted, the change in the TLC at follow-up was more pronounced (−12.2±10.3 vs −7.4±8.2; p=0.0163); similarly if the preoperative IVC was more than 75 percent of predicted, its reduction at follow-up was more pronounced (−9.0±9.7 vs −6.2±10.6), although not significant.

DISCUSSION

It has frequently been stated that pectus excavatum is purely a cosmetic problem and a number of publications have discussed related symptoms.1-14 Common symptoms include diminution of exercise tolerance, dyspnea on exertion, atypical chest pain, and frequent respiratory tract infection. One or more of these symptoms were present in a considerable number of our patients before surgery and significant improvement was noted in the majority at follow-up.5,17

Most of the studies on static preoperative pulmonary function in patients with pectus excavatum reported normal function3,9,11,19-22 or only moderate restrictive impairment, as expressed by a reduction in the IVC and TLC,7,10,23-25 especially in association with scoliosis.9 Our retrospective data also revealed a significant reduction in the IVC and TLC compared with the normal values for a particular age. At follow-up, we noted an increase in the TLC and IVC in absolute terms, probably due to growth, but a significant decrease when expressed as a percentage of predicted. In the ideal situation, we would be able to compare our group with patients who were followed up longitudinally without undergoing surgery. The alteration in lung volumes with increasing age in the latter group, however, might well be shown by the lung volumes before the operation in our patients, who were aged between 4.8 and 32.7 years. We did not find any significant relation between age and preoperative lung volumes (percent predicted). Therefore, lung volumes were decreased at a young age, but when expressed as a percentage of predicted, they did not show any further deterioration during growth.

Although some studies attributed symptomatic improvement after surgery to a demonstrable increase in the IVC and TLC,7,8 more recent studies, in contrast, reported a significant reduction in the IVC and TLC when expressed in percent predicted following cosmetically successful correction.9,10,15,25,26 This was due to increased postoperative chest wall restriction,26 ie, limitation of thoracic expansion by musculoarticular changes as a result of extensive surgery in the sternal region.9

A potential criticism on the present retrospective study is the great variation in time between surgery and the follow-up pulmonary function tests (2.7 to 17.9 years). However, as we found no significant relation between the preoperative lung volumes and age and no significant relation between postoperative change in lung volumes and the follow-up interval, it is likely that the increased restriction of pulmonary function was due to the operation. The reduction in lung function at follow-up was found to be most pronounced in the patients who had the least functional impairment preoperatively. Therefore functional improvement after surgery may be expected in patients with preoperative lung function values of less than 75 percent predicted,15 this was supported by our findings. We also found that increased restriction of lung function at follow-up was not correlated with age at surgery, the preoperative anteroposterior diameter of the chest, or the change in diameter at follow-up.

The FEV1 was found to be significantly different from the predicted values, although there was no significant difference when expressed as a ratio of the IVC. None of the previous studies were able to show an obstructive ventilatory defect in patients with pectus excavatum on the basis of the FEV1, the "Tiffenau test," or timed IVC measurements.1,3,5,24 If an obstructive ventilatory defect was present, we found it to be associated with one or more pulmonary...
complaints.

The change in the RV at follow-up as well as the RV/TLC ratio was significant, which indicated that the decrease in the TLC was due to both a decrease in the IVC and the RV.

The subjective physical improvement in most patients is difficult to explain. Despite a significant increase in the anteroposterior diameter of the chest, the lung volumes showed a definite decrease at follow-up. It is generally thought that the exercise capacity of normal subjects depends on their cardiac output. Patients with restrictive pulmonary disorders, such as pectus excavatum, may not be able to increase their ventilatory function as normal subjects can, because of restrictions in their chest wall mechanics. Several studies have presented data that pectus excavatum has a deleterious effect on cardiorespiratory function. It has also been shown that there was an increase in exercise performance, especially in an upright position, which could be attributed to favorable cardiac and hemodynamic effects of the operation, although no significant differences in work capacity were found after the operation. It is difficult to compare these studies because of differences in surgical techniques, study protocol, the lack of control groups, the relatively small number of patients, and various follow-up intervals. The possibility of subjective physical improvement secondary to psychological factors should be considered, although this relation has never been proved scientifically.

In conclusion, we performed a retrospective analysis of pulmonary function measurements on a large group of patients with long-term follow-up after surgical repair for pectus excavatum. Preoperative lung function values showed restricted pulmonary function, which was further aggravated by the operation. Pulmonary complaints may correlate with coincidental obstruction, but they do not correlate with preoperative restriction of the lung function. Although the correlation between the anteroposterior diameter of the chest and static lung function parameters was significant, the correlation coefficients were low. The satisfactory subjective long-term results of most of the patients justify surgery for psychologic/cosmetic reasons. Factors other than changes in lung volumes are probably responsible for the subjective physical improvement after surgery in most patients.

REFERENCES

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